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(72) Inventors HANS SMIT and
HANS PAASSEN

(54) METHOD FOR MEASURING AND EVALUATING ULTRASONIC TEST PULSES

(71) We, THYSSEN NIEDERRHEIN AG HÜTTEN- UND WALZWERKE, a Company organised under the laws of the Federal Republic of Germany, of 42 Oberhausen, Essener Strasse, 66 Germany, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method for measuring and evaluating ultrasonic test pulses of a selected pulse repetition frequency in the ultrasonic testing of plates and similar testpieces in accordance with the pulse-echo method with a plurality of SE (transmitter/receiver) test probes, where the defect echo and the bottom echo are displayed with the help of time "gates", taking into account the preliminary path of the pulse through the probe and the time the pulse takes to travel through the test piece; the defect echoes are standardised on the bottom echoes and their amplitudes measured and corrected by taking into account the pulse travel times as dictated by the associated characteristic curves for the depth. Considerable disadvantages apply to those methods of the kind described which are already known from practice. In order to make these understandable and to explain the problem on which the invention is based, let us first state the following:

In the pulse-echo method using SE test probes (SE=separate transmitter and receiver), separate short ultrasonic pulses of a selected repetition frequency are transmitted into the test piece and the reflections are picked up by a separate receiver. By means of Figure 1 the most important relations and definitions of this method are explained. In Figure 1a is outlined the principle of an SE probe when testing a plate. The pulse passes first from the transmitter through a path of synthetic material and is introduced into the plate via a water film. Reflections of the pulse take place at the top surface of the plate — this reflection is called the "top coupling echo" — and also at the defect and at the bottom of the plate. Figure 1b shows the reflectogram for this, with the transmitted pulse, the top coupling echo, the defect echo and the bottom echo. The time from the pulse being transmitted up to the botom echo being received corresponds to the total travel time of the pulse. When there is a defect in the test piece the pulse is entirely or partly reflected at the surface of the defect. In every case defect echoes have a shorter travel time then bottom echo and therefore they lie within the travel time through the test piece. This latter time is designated here as the "zone of expected defects". The beginning of this zone is indicated by the top coupling echo. The time between the transmission of the pulse and the top coupling echo corresponds to the pulse travel time in the preliminary path. The pulse travel time in the test piece of a known thickness d can be exactly calculated from the formula

$$t_{st} = \frac{2d}{c}$$

with the known speed of sound of c=5923 m/s. For example, the travel time of an ultrasonic pulse in a 20 mm thick plate amounts to 6.74 μs. The travel times in the path through the synthetic material and in the water film are different from one SE probe to another, and also are constantly variable on account of the wear which takes place in operation. The preliminary travel time of usual probes lies approximately between 15 and 20 μs.

In the evaluation of an ultrasonic pulse it is a requirement that as exact details as possible on the quality of the material through which the ultrasonic field passes should be obtained, that is to say to discover whether the material is free from defects or is affected by them. In order to arrive at this informa-

tion, the amplitude levels of the defect echo and the bottom echo must be measured. For this it is necessary to separate these echoes from the sequence of reflections and display them. Therefore, the first part of the task is to form time gates, as sketched in Figure 1b — FE (defect echo) display and RE (bottom echo) display. At the same time, the unit for producing the gates must first of all be able to be controlled via a computer according to the given thickness of the test piece, and secondly, the position of the defect gates within the travel time of the pulse must be able to be automatically controlled from one pulse to the next, so as to take into account the individual lengths of the preliminary paths of a number of probes and how they have been affected by wear. Therefore, with the solution of this problem there is also coupled the necessity of a high speed of control. According to the display of the defect echo and the bottom echo their amplitude levels can be measured. These measurements must take place for each individual test pulse, and therefore at a high speed. The absolute level of the defect echo is still not a direct measurement of the size of a defect situated in the ultrasonic field, as the echo level is essentially also dependent on two groups of influencing factors.

The first group is connected with the generating, the spread and the reception of the ultrasonic field. The level of the defect echo is dependent on:

the sensitivity of the SE probe,
the couplant conditions,
and also the distance of the defect from the SE probe.

The second group covers the values which relate to the nature of the defect, such as:

the shape of the defect,
the reflection coefficient,
the characteristics of the surface of the defect, and
the inclination of the plane of the defect to the ultrasonic beam.

From what has been said it follows that the next task is to eliminate the aforesaid influencing factors in a suitable manner.

In the first group of influencing factors, the level of the defect echo has to be related to the bottom echo level in order to compensate for the differences in sensitivity between the individual SE probes due to variations in manufacture and individual wear, and the time variations in ultrasonic transmission. The bottom echo is, in fact, dependent on the sensitivity of the probe and on the couplant conditions in approximately the same way as is the defect echo. The dependence of the defect echo and the bottom echo on the distance away of the defect must be eliminated by a correction of both echo levels in accordance with the depth characteristic curves of the probes.

The influencing factors in the second group relating to the nature of the defect can be taken into account in the first place by using the method of digitally scanning the defects by pulses, with a relatively narrow ultrasonic beam and secondly by logically combining several pieces of test information obtained from successive points and discriminated by means of two or more threshold values. The logical combination must be performed in a data processing stage. It is not, therefore, further discussed here.

After eliminating the influencing factors of the first group, the task is concluded by carrying out the determination of the size of the defects by means of discriminators.

The generation of ultrasonic pulses and the reception and display of the reflections have long been known technically. The evaluation of the ultrasonic pulses, i.e. seeking out the information contained with due account being taken of the aforesaid influencing factors of the first group, can be carried out by an observer with the help of indicating instruments such as, for example, an oscilloscope or ultrasonic testing instruments which can be compared to specialised oscilloscopes. This kind of evaluation has the decided disadvantage that it is very time-consuming and can be carried out only statically, so to speak. For objective, automatic ultrasonic testing, what are known as "monitors" are used, these forming part of the present state of the art. These monitors produce the time gates for the zone of expected defects, and also for the bottom echo. This gate control has the disadvantage that it can be adjusted for the preliminary path and the thickness of the material only by hand or by means of a relatively slow-working control system. When several SE probes are being used, it is a disadvantageous requirement that all the SE probes must have similar preliminary paths. The monitors also have one or more trigger thresholds for discriminating the defect echoes which are found.

For compensating for the sensitivity of the probe and variations in the couplant conditions by relating the defect echo to the bottom echo, the already known "gain control" method is used. In this way of controlling an amplifier a certain number of bottom echoes are integrated together and the amplification for the succeeding reflections is adjusted to the average value of this integration. When using several SE probes the possibility exists of obtaining an average value of the bottom echoes of all the SE probes used and at the same time admitting for the integration only those bottom echoes which have been reflected from a defect-free place. That is to say, the unaffected bottom echo is taken as the reference value on which the already known AVG diagrams (A=distance away;

V=amplification; G=size of defect) are based.

This method of standardising the defect echo on the bottom echo has, however disadvantages: the regulation is by its very nature relatively sluggish. In order to obtain an average value by integration, experience has shown that some 10 pulses are necessary. Sudden alterations in the couplant conditions cannot be dealt with by this type of regulation. This kind of regulation always demands extrapolation of previous pulses onto the succeeding ones, and reflections from separate places.

It is true that for compensating for the depth characteristic curves, automatic electronic methods have been known, in which the amplifiers are controlled with given characteristics according to the pulse travel time. However, any desired complicated characteristic curve functions, such as are found with SE probes, cannot be compensated. Besides this, account is not taken of the fact that the characteristic curves for defect echoes differ from those of bottom echoes, as the echoes obey different laws.

To sum up, there are the following disadvantages and failings in the known methods and instruments for solving the problem previously described:

The creation of short time gates, which are necessary for displaying the defect echo and the bottom echo, is, as regards their position and duration, only possible by hand or by slow-working control circuits. With this, it is necessary to have the same preliminary paths for all the SE probes used. It is not possible to take direct account of wear on the probes. Therefore the maintenance expenses for a number of SE probes become unbearably high.

The method of standardising onto the bottom echo, the so-called "gain control", is too sluggish. It does not take into account the pulse which is actually travelling and which should be used for the measurement, but relies on pulses which are separated from this in both time and place, the result being that for the reference value there is obtained an average value.

Defects which are situated close to the surface, and also the kind of defect in which only slight reflection takes place, are not indicated when the gain control is based on an undisturbed bottom echo. If the gain control relies on the bottom echo being disturbed by the defect, then there are the disadvantages that in the first place each individual SE probe must have its own gain control unit, and secondly that the indication of the kinds of defect just mentioned is uncertain, because of the sluggishness of the method. There is no automatic ascertaining of the depth at which the defect is situated, nor any compensation of the defect echo and the bottom echo in accordance with whatever depth characteristic curve is associated with the probe.

Looked upon as a whole, therefore, there is so far neither method nor apparatus known with which the requirement laid down at the beginning could be conclusively solved, nor does a combination of the separate, known parts of methods satisfy the requirement.

Against this, the problem on which the invention is based is to develop a method for the automatic measuring and processing of ultrasonic pulses, particularly suitable for use in ultrasonic testing equipment with a number of SE probes and electronic data processing equipment, in which the aforesaid disadvantages and failings of known parts of methods are avoided.

According to the present invention, there is provided a method for measuring and evaluating ultrasonic test pulses of a selected pulse repetition frequency in the ultrasonic testing of plates and similar test pieces by means of the pulse-echo method with a plurality of SE (as hereinbefore defined) test probes, where the defect echoes and bottom echoes are displayed within time gates, taking into account the preliminary path of the pulse through the probe and a coupling medium and the time the pulse takes to travel through the test piece, the defect echo amplitudes being standardised by the bottom echo amplitudes and the defect echo and bottom echo amplitudes being measured and corrected as dictated by the associated characteristic echo-amplitude compensation-depth curves, by taking into account the travel times, wherein the preliminary paths of all the SE probes are individually and successively ascertained automatically in time with the pulse repetition frequency by counting out the total pulse travel time from transmission of a pulse to reception of a bottom echo with a high counting frequency and electronically obtaining the differential between the total pulse travel time and the pulse travel time solely through the test piece and storing the preliminary paths in a memory as a number of oscillations: the time gates being created by counting out at the aforesaid counting frequency; the maximum amplitudes of the maximum defect echoes and of the bottom echoes being automatically determined for each pulse and being digitally stored in a corresponding echo level memory, the travel time of the maximum defect echo per pulse being established by automatically counting out the counter frequency; the corrections of the defect echoes according to the travel time being carried out by using the travel time as a director for consulting a table stored in an electronic memory, this table being programmed with a corres-

ponding echo-amplitude compensation-depth characteristic curve function; and the standardising of the defect echoes by the associated bottom echoes being, by logarithmic measurement of the echo levels, reduced to a subtraction, this being performed by simultaneously counting out the echo level memories and obtaining the count differential, which is stored in a counter, the relationship of the defect echo to the bottom echo being discriminated by one or more thresholds.

By this, the relationship defect echo/bottom echo, or respectively their logarithmic differential, can easily be indicated in figures and discriminated by means of digital comparators. The total travel time of the pulse, the pulse travel time through the preliminary path, the defect echo travel time and the bottom echo travel time can be stored in respective memories in a binary code. The simplest way of creating the time gates is to take the stored preliminary paths of each SE probe and also the thickness of the test piece as the values which have to be counted out. Generally in the method of the invention, the amplitudes of the maximum defect echoes and of the bottom echo will be digitally and logarithmically stored and indicated. The pulse travel time from the test piece surface to a defect or to the bottom of the test piece too can be indicated in figures. Generally it is recommended that in addition a correction of the bottom echoes should be carried out by using the thickness of the test piece as the director for consulting a table stored in a further electronic memory, this table being programmed with a corresponding characteristic curve function.

In other words, the invention by the above features and by further features makes possible as a whole;

- the determining and storing of the preliminary paths of all the SE probes;
- the creation of time gates for displaying defect echoes and bottom echoes;
- the measuring of the amplitudes of defect echoes and bottom echoes;
- the ascertaining of the travel times of the defect echoes;
- the correction of defect echoes and bottom echoes in accordance with given depth characteristic curves;
- the finding of the relationship of the defect echo to the bottom echo;
- the discrimination of the relationship of the defect echo to the bottom echo.

The preliminary paths of all the probes are individually, successively and automatically ascertained, in time with the pulse repetition frequency (up to about 20 KHz depending on the thickness range of the plates), by counting out the pulse travel time with a high frequency (about 30 MHz) and obtaining electronically the differential between the total pulse travel time and the time the pulse takes to travel through the test piece and are stored away in the binary code as a number of oscillations. After that, the creation of the time gates is done likewise by counting out the aforesaid high frequency, the stored preliminary paths for each probe and also the test piece thickness being used as the values to be counted out. The determination of the amplitudes of the maximum defect echo and of the bottom echo is automatically carried out practically simultaneously for each individual pulse, the measuring being done digitally and logarithmically, e.g. in dB, and the measurements being stored and indicated in figures. When the pulse voltage rises there is also given, per dB stage, a signal for determining the travel time. Ascertaining the travel time of the maximum defect echo per pulse is likewise done by counting out the aforesaid high frequency, the last of the signals just mentioned marking the end of this travel time.

The travel time is indicated in figures. The correction of defect echoes according to the depth of their position is carried out by means of the measured travel time by using the latter as the director for consulting a table stored in an electronic memory, this table being able to be programmed with any desired characteristic curve function. The correction for the bottom echoes is carried out in a second table, correspondingly programmed, and in this case the test piece thickness is used as the director. The dividing of the defect echo level by the bottom echo level is reduced to a subtraction because the echo levels are measured logarithmically; this is done by simultaneously counting out the contents of the echo level memories, controlled in such a way that the differential between the levels is fixed in a counter. The reference value of the relationship is therefore the bottom echo affected by the defect. The relationship or defect echo/bottom echo, or respectively their differential, in dB, is indicated in figures and directly discriminated by means of any desired number of digital comparators.

The result is first that all the disadvantages of the known methods are obviated, and the problem on which the invention is based is solved. By relating the defect echo to the defect-disturbed bottom echo for each individual testing pulse there is also a particularly outstanding advantage, for even those defects are indicated which produce only a slight echo but which cause the collapse of the bottom echo because of their shadowing effect. The fact is that when the reference value becomes very small, the defect echo too can be correspondingly small. This includes defects which are situated very close to the surface, and which therefore lie in the dead zone, and also those kinds of defect in which only slight reflections occur because of sound-ab-

sorption, but in which the bottom echo is completely absorbed.

An advantage of the through-transmission method is obtained, without having to put up with the disadvantages. The invention also covers, in case it is desired or necessary for other SE probes or test pieces, using the undisturbed bottom echo as the reference.

The question of whether relating the defect echo to the disturbed bottom echo results in a usable relationship, which makes possible an unambiguous determination of the size of defects, may be answered by means of Figure 2. Figure 2 shows the curve for the depth-corrected echo level ratio of the defect echo to the disturbed bottom echo. Different depths of defect were selected as the parameters. The thickness of the test piece was 24.6 mm. The bottom echo correction is standardised on the bottom echo of a plate of 18 mm, because the focus point of the probe lies in 18 mm depth. It can be seen from Figure 2 that up to a defect of 4 mm the standardised curves do not deviate appreciably from each other. If therefore a threshold is set — as is customary in practical testing — at about 3 to 4 mm plain drilled hole, this has the same value for every defect position. When the defects are larger the curves part from each other, in particular the curve for the mid position (12.3 mm) shows a great deviation because in this case the second defect echo, instead of the bottom echo takes over the role of the reference value. However, it is of no interest here beyond giving a general indication to known how the curves run above the threshold value.

The invention will now be described in greater detail, by way of example, with reference to the accompanying drawings, in which:—

Figure 3 shows schematically the functional construction of an ultrasonic pulse measuring and calculating instrument according to the invention;

Figure 4 shows the principle of the gate control for the instrument of Figure 3.

Figure 5 is a schematic explanation of the determination of the amplitudes of the defect echo and bottom echo and also of the standardising, and

Figure 6 is a schematic explanation of the depth curve compensation.

The measuring and calculating instrument, represented in Figure 3 contains the following functional units:

The governing equipment:

This is the pacemaker of the whole instrument and essentially contains components which reduce a given timing frequency, which here is 30 MHz, to the different low control frequencies necessary for the gate control.

The gate control.

In this block are created the necessary time gates for displaying the zone of expected defects and the bottom echo. It is from the gate control that the two groups of functions i.e. travel time measurement and echo level measurement are controlled.

The echo level measurement.

In this unit, which is directly connected to the receiving side of the SE probe, the defect echo levels and bottom echo levels are measured.

The relationship formation.

Here the echo level ratio between the maximus defect echo and the bottom echo of one and the same pulse is formed.

The travel time measurement.

Here is measured the travel time of the defect pulse from the moment the injected pulse enters the top of the test piece until the largest defect pulse reaches its maximum.

The depth characteristic curve compensation.

In this unit is determined the depth correction for the defect echo level, based on the ascertained travel time, and also the correction for the bottom echo level, based on the given plate thickness. The two correction values are passed on to the relationship formation unit during the relationship formation and before the end of the pulse travel time.

The defect discrimination.

This stage consists of any desired number of adjustable threshold values in the form of digital comparators. The "Yes—No" information from the digital comparators is passed on to the computer.

The governing equipment contains a 30 MHz oscillator. From this frequency are derived all the timing frequencies necessary for controlling the counters, memories and registers (see below). By means of a multiplexer, for each individual SE probe in succession not only are the pulses released but also the preamplifier for the relevant receiver is switched-in. In addition, with the same timing, the preliminary path memory is activated for giving out the corresponding preliminary path time.

The problem of the gate control first raises the question of the method of time measurement. Time measurement of any desired accuracy can be achieved by using a correspondingly high frequency. In the present case, of course, a very high counting frequency is used, as can be seen from the extremely short pulse travel times (6.74 μ sec for a test piece thickness of 20 mm). If the defect gate setting is required to have a resolution of 0.1 mm in a steel test piece, the result is a counting frequency of about 30 MHz — that is to say

one 30 MHz oscillation corresponds to the pulse travel time through 0.1 mm of steel, there and back. The principle of the gate control is shown in Figure 4. The start of each individual testing operation is initiated by the transmitter pulse. Fundamentally, as soon as the pulse dies away at the transmitter the monitoring display could be opened, and closed again shortly before the bottom echo. However, in view of possible interference by electromagnetic pulses the display time should be as short as possible. Therefore, the gate is not opened until after the expiry of the preliminary travel time, as is shown in Figure 4 on the left. This means that the preliminary travel time must be exactly known. But this depends in each individual case on the SE probe and on the wear which has taken place. Therefore it is necessary regularly to determine the amount of the preliminary path time, which here is designated as t_v. By measuring the travel time on a test piece of known thickness this time can be ascertained by subtracting the travel time through the test piece e.g. steel plate, which can be calculated exactly and is here shown as t_{st}, from the measured total travel time t_{ges}. There are two distinct operational phases, namely the *measuring phase* — shown in Figure 4 to the left of the dashed line — in which the preliminary path of each individual probe is ascertained by means of a test piece and stored in a memory, and the *testing phase* — on the right in Figure 4 — in which during the testing operation, separately for each individual SE probe, the gates are formed from the values stored in the memory and from the thickness of the test piece e.g. the plates being examined. In the measuring phase the SE probes are applied to a test plate of a known thickness. The given test plate thickness is pre-set in a counter — here designated as the "preliminary path counter, forwards" — as the amount to be subtracted in the formula written on the diagram, that is to say $(-t_{st})$. In practice this is done in such a way that t_{st} is set as the complement to the maximum counting capacity of the counter. If, for example, the maximum counting capacity is 10,000, then in the case of a test plate thickness of, for example, 20 mm, corresponding to 200 oscillations of the generator, the counter is set to 9,800. The governing equipment releases the transmitter pulse and simultaneously starts up the "preliminary path counter, forwards". This runs in the forward direction. As it was pre-set negatively, it runs up to 10,000. When it reaches its maximum counting capacity it has therefore counter 200 oscillations, that is to say the travel time for the test plate thickness. The further counting period up to the bottom echo now corresponds to the preliminary path. After the bottom echo has stopped the counter, the time t_v, corresponding to the preliminary path, is present in the counter. It is immediately taken up into the preliminary path memory, which is made as a shift register. In the same way the preliminary paths of the other SE probes are measured and stored in the memory. With this, the measuring phase is concluded. Corrections of the gate times to take into account the leading edges of the bottom echoes and also the tolerances on the test plate thicknesses are carried out by means of the already known value for the thickness of the test plate.

In the testing phase the time gates are formed by a chain of counters which are set up with suitably different counting times. Each counter counts out its pre-determined time, and after its "count down" starts up the next counter. First of all the "preliminary path counter, backwards" is set to the preliminary path of the first SE probe and is then started up by the governing equipment, at the same time as the transmitter pulse. This counter runs backwards. When it reaches zero, the preliminary path has been counted down. A pulse is given out by the counter by which the defect gate is opened, that is to say at the end of the preliminary path — which is equivalent to the beginning of the zone of expected defects. But this pulse also simultaneously starts up the "plate thicknesses counter". This is set to the thickness of the plate being examined at that time. When this counter reaches zero the defect gate is closed, and simultaneously a "dead gap counter" is started up. The dead gap produced here between the defect gate and the bottom echo gate is necessary for the control operations for the measurement of the echo levels. After the "count down" of the dead gap counter the bottom echo gate is started up, and the bottom echo gate is counted down by the "bottom echo gate counter" in a manner corresponding to the previous time gate formations. For controlling the echo level measuring unit the time-gates for the defect echo (FE) and the bottom echo (RE), each individually, and a through-going time gate from the start of the zone of expected defects up to the end of the bottom echo are still needed. These gate configurations are shown in Figure 4 at the top right hand side.

In Figure 5 are illustrated the various steps for measuring the echo levels, the formation of the relationship between the defect echo and the bottom echo, and the defect discrimination. The pulses picked up by the receiver are first amplified. Below the receiver there is the pulse diagram of a single ultrasonic probing operation, with the transmitter pulse, the top coupling echo, the defect echo and the bottom echo being indicated. The ultrasonic oscillations are in this case not rectified. Actually, the transmitter pulse might not appear at the receiver, but in most cases it is

present as electro-magnetic coupling. From the time standpoint this sequence of echoes enters the amplifier in the reverse order from what is shown here, which has been done to take account of the customary display on the oscilloscope. The amplified signals are passed on to a chain of comparators. This chain of comparators serves as a rapid digital voltmeter. The measuring unit consists of 80 comparators which, like trigger stages, flip over when a fixed pre-set reference voltage is reached. In order to be able to reduce the subsequent calculating operation, namely the division of the defect echo by the bottom echo, to a subtraction which is simple to carry out electronically, the reference voltages are built up logarithmically by voltage dividers in such a way that they each differ from the next comparator by 1 dB. Thus the voltage measurement is performed with an accuracy of 1 dB, which is fully adequate for ultrasonic purposes. The response speed of these comparators is higher by at least a factor of 4 than the leading-edge-rise-speed of a 4 MHz pulse. As an example, a bottom echo pulse is shown in the drawing in the comparator chain. The peak of the pulse, which was received at 4 dB, has caused all the comparators from 5 to 80 dB to flip over (0dB corresponds to an unweakened signal). Since, after the passage of the ultrasonic pulse, the comparators flop back, the state of the comparator chain during the passage of the pulse is retained by amplitude memories, which are connected to the individual comparators. The peak voltage of the pulse is fixed in the memory. As shown in Figure 5 the memory is activated by the gate control only during the ranges where the defect echo and the bottom echo are to be expected. This memory for the amplitudes of the defect echo-bottom echo represents as it were an intermediate memory for the defect echoes and bottom echoes which arrive one after the other. It is always discharged when there is no time gate present, and therefore in the dead gap between the defect echo gate and the bottom echo gate. The defect echoes and bottom echoes are separately stored in the corresponding 80 bit shift registers shown alongside. Each value in the memory is transferred simultaneously in a parallel manner. The transfer is controlled by the gate control unit (represented symbolically in Figure 5 by the pulse sequence FE gate/RE gate), by means of the defect echo gate in the case of the defect shift register and by means of the bottom echo gate in the case of the bottom echo shift register. At the end of the pulse travel there is, in the defect shift register, the highest pulse which has passed through the zone of expected defects, and in the bottom echo register the height of the bottom echo pulse, both being digitally expressed in dB. Therefore, whilst the comparators flip over as the pulse rises and flop back, as the pulse passes on, the memories and shift registers retain the pulse peaks; each intermediate memory retains them only during the zone of expected defects and the time of the bottom echo gate respectively, but the shift registers still retain them after the expiry of the time gates. The echo levels are now read off in series from the shift registers by means of two counters with a generator frequency of 15 MHz. The registers are counted down, starting with the low amplification values. Both counters are stopped by the first memory which holds a "yes" piece of information. The count down of both memories takes place simultaneously. Therefore, in the defect echo shift register six empty memories are counted =6 dB, and in the bottom echo shift register four empty memories=4 dB. These numbers are visually indicated in figures. The count down of the echo levels is done as soon as the defect echo gate, the dead gap gate and the bottom echo gate no longer exist, this being symbolized in Figure 5 by the total gate pulse. With this the operation of echo level measurement, both for the defect echo and the bottom echo, is concluded. By means of an adjustable digital comparator, not shown in Figure 5, a minimum height for the bottom echo is monitored as a criterion for any defect in the probe.

In order to form the echo level ratio of the defect echo and the bottom echo, i.e. in order to carry out the standardisation, a further counter, here called the "relationship counter", is started by means of a start/stop logic as soon as either the defect echo counter or the bottom echo counter has finished counting the echo level. The relationship counter then counts out 15 MHz oscillations until the other echo level counter has likewise stopped. It has therefore counted out the number of oscillations, i.e. 1 dB steps, which lie between the defect echo and the bottom echo, and therefore calculates the relationship of the echo levels in dB. The mathematical sign for this relationship is quite simply given by determining whether the defect echo counter or the bottom echo counter has stopped first. The relationship in dB is indicated in figures, together with the mathematical sign. If the sign is negative the defect echo is smaller than the bottom echo. The relationship counter is pre-set as shown in Figure 5, with a correction value from the depth curve compensation. In this case, therefore, the relationship value is not $6-4=2$, but 7, because in the example here it has been assumed that the correction value is 5.

Before the correction for the compensation can be ascertained, the pulse travel time must be measured. The travel time measuring unit is so conceived that the determination of the time takes place at the point of the maximum defect echo level. In order to make this pos-

sible, the memory for the amplitudes of the defect echo and the bottom echo is made in such a way that when any memory element flips over, a needle pulse is generated, as is shown in Figure 5 above the memory. As long as an ultrasonic echo is arising, and by this the elements of the memory are being set, needle pulses occur here one after the other. The last needle pulse which occurs in the zone of expected defects indicates the point in time of the passage of the highest echo peak. By this is immediately given the most important pre-requisite for determining the travel time of the maximum defect echo. As Figure 6 shows, this pulse is passed on to an acceptance memory which accepts, together with the pulse, the momentary counting state of a counter running at 30 MHz. This counter is started up at the beginning of the defect display. Both the counter and the acceptance memory are only activated for the duration of the defect gate (see "not" in Figure 5). From the acceptance memory the travel time is indicated digitally in mm. Acceptance takes place at every pulse which causes the memory to flip over, i.e. even during the rise time of an ultrasonic reflection. Each previous value in the memory is cancelled by the succeeding one. Therefore, the final pulse brings about the acceptance of the counting time which corresponds to the travel time of the pulse peak.

From the acceptance memory the time value is passed on as a binary director to the memory containing the defect characteristic curves. In this memory, elements which contain correction values for any required characteristic curve are available to the directors (the directors corresponding to the defect depths). From this table, after the director has been fed in, the correction value is held in readiness at the output of the memory. Since the characteristic curves for the defect and for the bottom of the test piece are different, a second similar memory is necessary for the characteristic curves of the bottom echo. This is programmed in such a way that the plate thickness coming from the computer is put in as the director, and the bottom echo correction value in dB is held in readiness at the output. The two correction values are subtracted from each other in a subtractor, and the result, being the total correction value and therefore the pre-setting for the counter, is already prepared before the expiry of the total travel time of the pulse, that is to say already before the absolute value for the bottom echo has been ascertained in the echo level measuring unit. With this, the depth curve correction is concluded, both for the defect echoes and for the bottom echoes.

The defect discrimination still remaining in Figure 5 is done by means of digital comparators. Here the relationship value is compared with threshold values set digitally by hand or by computer, and when the threshold value is exceeded in any comparator stage it is recognised for a defect. The digital test information so obtained is passed on to a computer and may be displayed.

In the example, the method as a whole is tailored to the testing of plates; transferring it to other types of test pieces is possible by changing the corresponding parameters. Although the instrument described for carrying out the method given in the invention is conceived for computer-controlled installations, it can also be used in conjunction with simple recording equipment or for manual testing.

WHAT WE CLAIM IS:—

1. A method for measuring and evaluating ultrasonic test pulses of a selected pulse repetition frequency in the ultrasonic testing of plates and similar test pieces by means of the pulse-echo method with a plurality of SE (as hereinbefore defined) test probes, where the defect echoes and bottom echoes are displayed within time gates, taking into account the preliminary path of the pulse through the probe and a coupling medium and the time the pulse takes to travel through the test piece, the defect echo amplitudes being standardised by the bottom echo amplitudes and the defect echo and bottom echo amplitudes being measured and corrected as dictated by the associated characteristic and echo-amplitude compensation-depth curves, by taking into account the travel times, wherein the preliminary paths of all the SE probes are individually and successively ascertained automatically in time with the pulse repetition frequency by counting out the total pulse travel time from transmission of a pulse to reception of a bottom echo with a high counting frequency and electronically obtaining the differential between the total pulse travel time and the pulse travel time solely through the test piece and storing the preliminary paths in a memory as a number of oscillations; the time gates being created by counting out at the aforesaid counting frequency; the maximum amplitudes of the maximum defect echoes and of the bottom echoes being automatically determined for each pulse and being digitally stored in a corresponding echo level memory, the travel time of the maximum defect echo per pulse being established by automatically counting out at the counting frequency; the correction of the defect echoes according to the travel time being carried out by using the travel time as a director for consulting a table stored in an electronic memory, this table being programmed with a corresponding echo-amplitude compensation-depth characteristic curve function; and the standardising of the defect echoes by the associated bottom echoes being, by logarithmic measurement of the echo levels, reduced to a subtraction, this being performed by

simultaneously counting out the echo level memories and obtaining the count differential, which is stored in a counter, the relationship of the defect echo to the bottom echo being discriminated by one or more thresholds.

2. A method as claimed in Claim 1, wherein the relationship of defect echo amplitude divided by bottom echo amplitude, or respectively their logarithmic differential, is indicated in figures and discriminated by means of digital comparators.

3. A method as claimed in Claim 1 or Claim 2, wherein the total travel time of the pulse, the pulse travel time through the preliminary path, the defect echo travel time and the bottom echo travel time are stored in respective memories in a binary code.

4. A method as claimed in any preceding Claim, wherein, when creating the time gates the preliminary paths of each probe, stored in a memory, and also the thickness of the test piece are used as the values which are to be counted out.

5. A method as claimed in any preceding Claim, wherein the amplitudes of the maximum defect echo and also of the bottom echo are stored and indicated digitally and logarithmically.

6. A method as claimed in any preceding Claim, wherein the pulse travel time from the test piece surface to a defect or to the bottom of the test piece is also indicated in figures.

7. A method as claimed in any preceding Claim, wherein a correction for the bottom echoes is carried out by using the thickness of the test piece as the director for consulting a table contained in a further electronic memory, this table being programmed with a corresponding echo amplitude compensation-depth characteristic curve function.

8. A method for measuring and evaluating ultrasonic test pulses of a selected pulse repetition frequency in the ultrasonic testing of plates and similar test pieces substantially as hereinbefore described with reference to Figures 3 to 6 of the accompanying drawings.

HULSE & CO.
Chartered Patent Agents,
Cavendish Buildings,
West Street,
Sheffield S1 1ZZ

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TESTING SET-UP

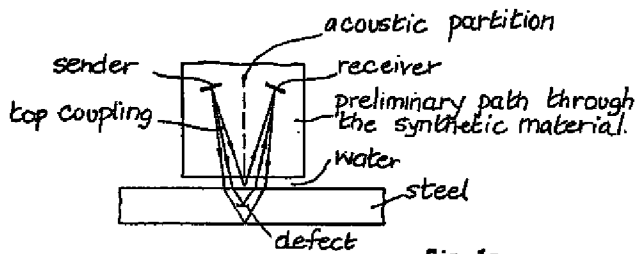


Fig. 1a

REFLECTOGRAM

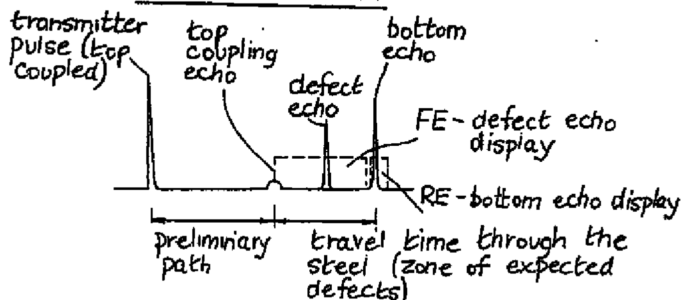
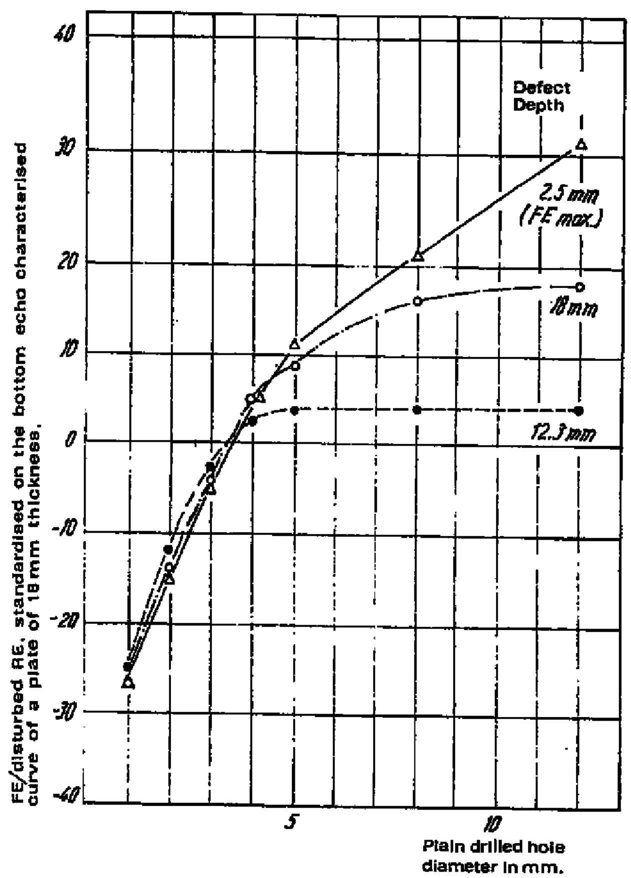


Fig. 1b

Fig. 2


40
30
20
10
0
-10
-20
-30
-40
FE/disturbed RE, standardised on the bottom echo characterised curve of a plate of 18mm thickness.
Defect Depth
2.5 mm (FE max.)
18 mm
12.3 mm
5
10
Plain drilled hole diameter in mm.

1402495 COMPLETE SPECIFICATION

6 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 3

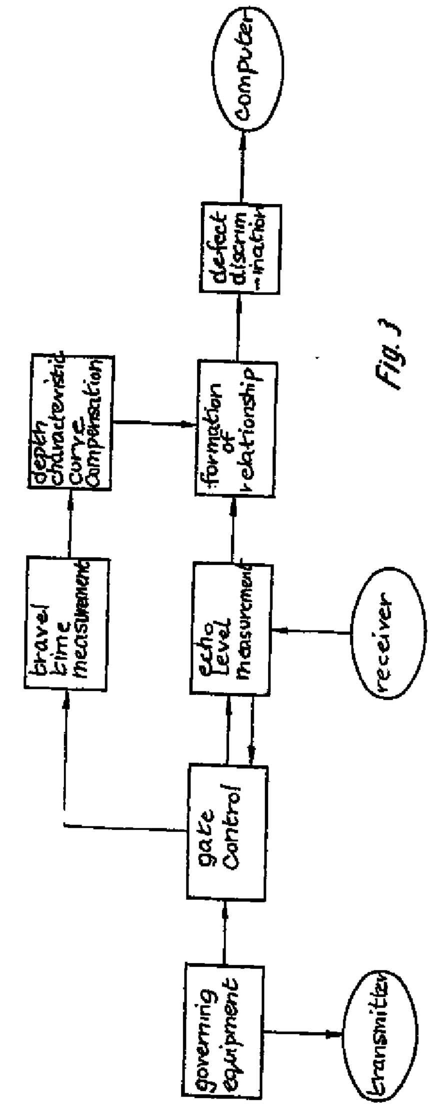


Fig. 3

1402495 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

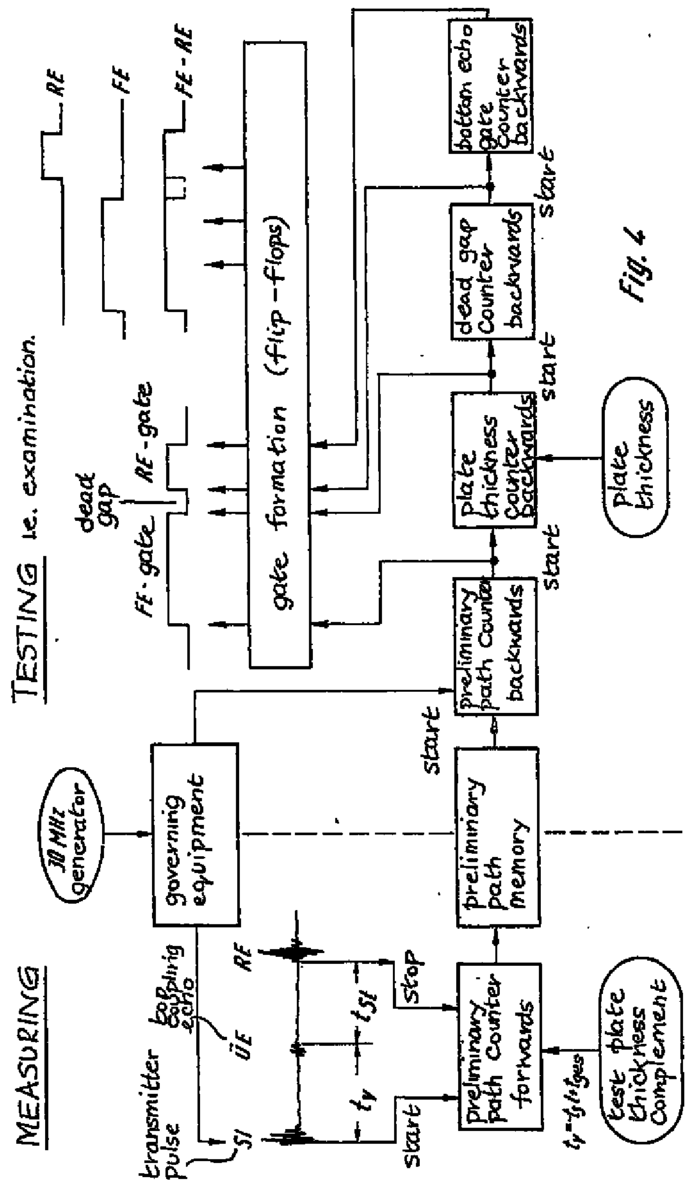


Fig. 4

1402495 COMPLETE SPECIFICATION

6 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 5

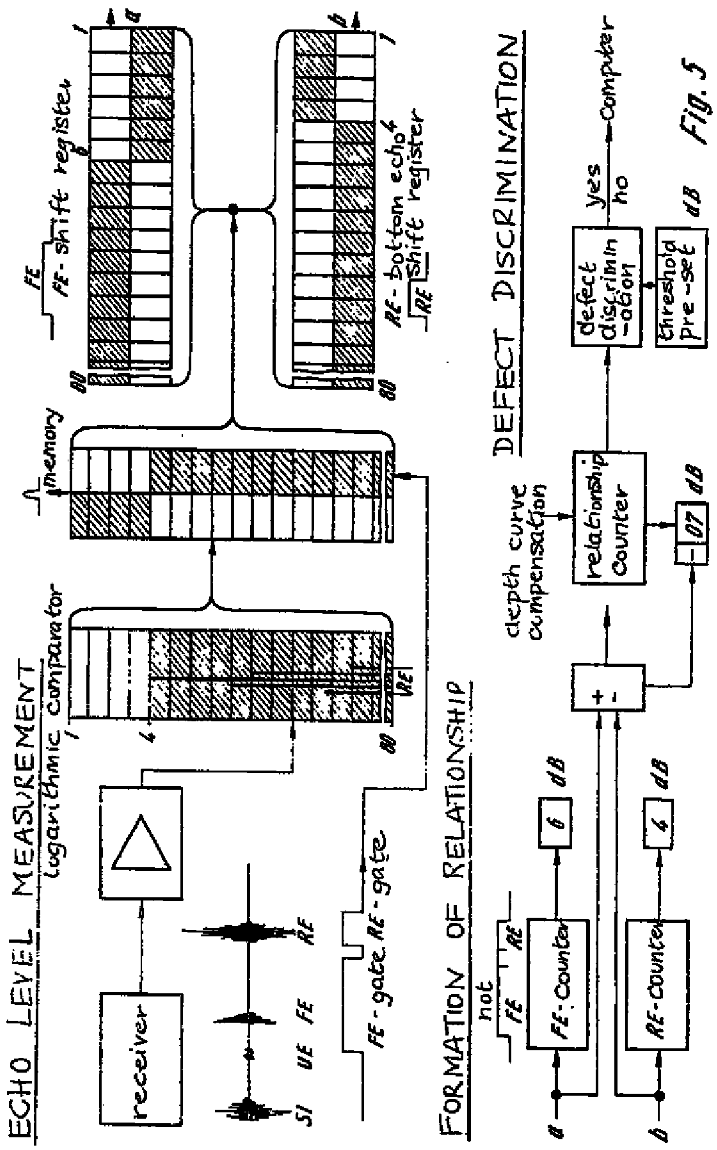


Fig. 5

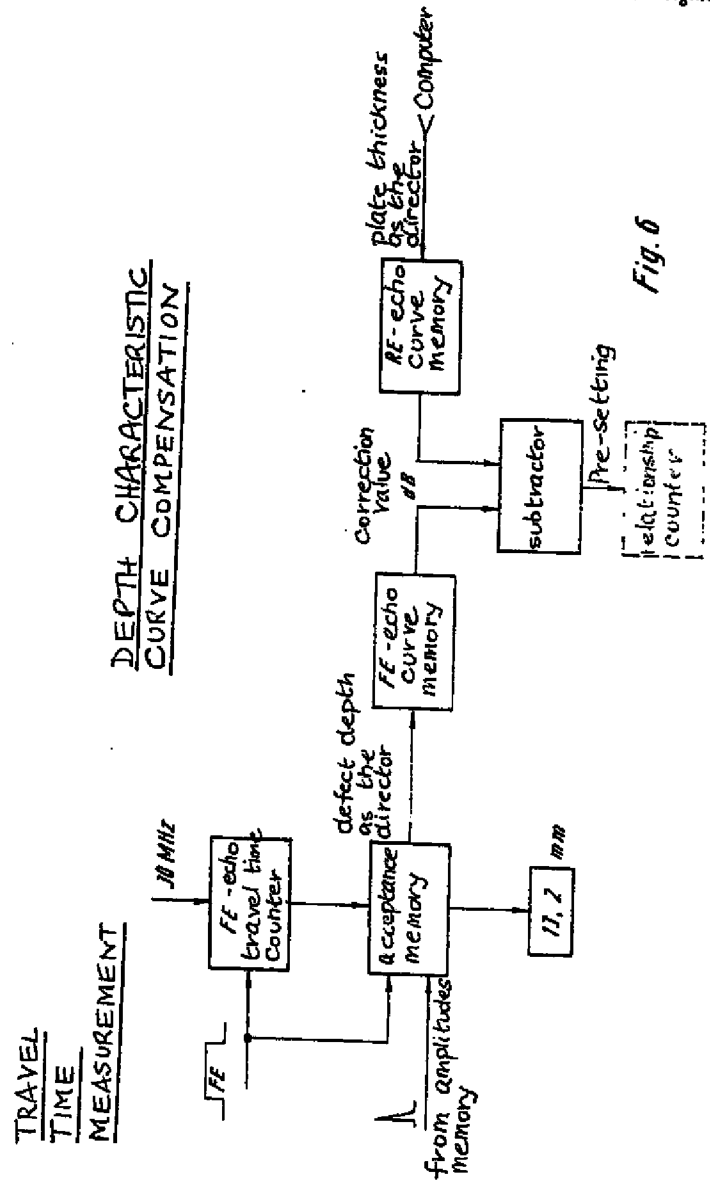

TRAVEL TIME MEASUREMENT
DEPTH CHARACTERISTIC CURVE COMPENSATION
10 MHz
FE
FE-echo travel time Counter
acceptance memory
from amplitudes memory
17,2
mm
defect depth as the director
FE-echo curve memory
Correction value dB
subtractor
Pre-setting
relationship counter
RE-echo curve memory
plate thickness as the director
Computer

Fig. 6